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Validate the Solution

Charges in the microcoulomb range are expected to exert moderate forces on each other.

PRACTICE PROBLEMS

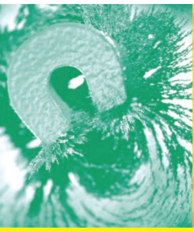
1. Calculate the electrostatic force between charges of $-2.4\ \mu C$ and $+5.3\ \mu C$, placed 58 cm apart in a vacuum.

2. The electrostatic force of attraction between charges of $+4.0\ \mu C$ and $-3.0\ \mu C$ is 1.7×10^{-1} N. What is the distance of separation of the charges?

3. Two identically charged objects exert a force on each other of 2.0×10^{-2} N when they are placed 34 cm apart. What is the magnitude of the charge on each object?

4. Two oppositely charged objects exert a force of attraction of 8.0 N on each other. What will be the new force of attraction if the objects are moved to a distance four times their original distance of separation?

5. Two identical objects have charges of $+6.0\ \mu C$ and $-2.0\ \mu C$, respectively. When placed a distance d apart, their force of attraction is 2.0 N. If the objects are touched together, then moved to a distance of separation of $2d$, what will be the new force between them?



QUICK LAB Graphical Analysis of Coulomb's Law

TARGET SKILLS

- **Analyzing and interpreting**
- **Communicating results**

In this Quick Lab, you will use sample data to gain practice with the inverse square dependence of the electrostatic force between two point charges on the distance between them. Two equally charged, identical small spheres are placed at measured distances apart and the force between them is determined by using a torsion balance. Prepare a table similar to the one shown here, in which to record your data.

1. Draw a graph of force versus distance for this data. What is the shape of this graph?

2. Rearrange the distance data (use the third column in your table) and draw a graph that shows the relationship as a linear one (refer to Skill Set 4, Mathematical Modelling and Curve Straightening).

3. Measure the slope of the straight line.

4. Using the known value of Coulomb's constant ($k = 9 \times 10^{9}\ \mathrm{N \cdot m^2/C^2}$), calculate the value of the original charge on the spheres.

Force ($\times 10^{2}$ N)	Distance between centres (cm)	
5.63	1.2	
2.50	1.8	
1.30	2.5	
0.791	3.2	
0.383	4.6	
0.225	6.0	

The Nature of Electric, Magnetic, and Gravitational Forces

All forces, including electrostatic forces, are vector quantities and obey the laws of vector addition. The equation describing Coulomb's law uses only scalar quantities, with the understanding that the direction of the force always lies along the line joining the centre of the two charges. However, when one charge experiences a force from more than one other charge, the direction must be resolved.

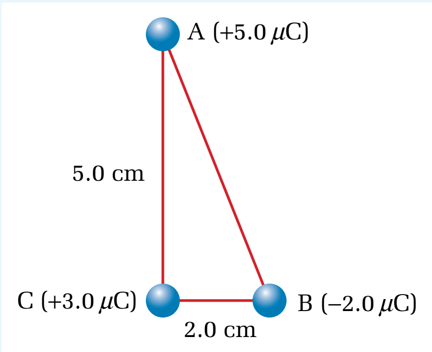
ELECTRONIC LEARNING PARTNER

Go to your Physics 12 Electronic Learning Partner to enhance your knowledge of Coulomb's law.

SAMPLE PROBLEM

Multiple Charges

Three charges, A (+5.0 μC), B (–2.0 μC), and C (+3.0 μC), are arranged at the corners of a right triangle as shown. What is the net force on charge C?



Conceptualize the Problem

- *Charges* A and B both exert a *force* on C.
- Although A and B exert forces on each other, these forces have no effect on the forces that they exert on C.
- The *net force* on charge C is the *vector sum* of the *two forces* exerted by charges A and B.
- The *forces* exerted by A and B are related to the magnitude of the *charges* and the *distance* between the charges, according to *Coulomb's law*.

Identify the Goal

The net force, $\vec{F}_{\text{net}}$, on charge C

Identify the Variables and Constants

Known		Implied	Unknown
$q_A = +5.0 \times 10^{-6}$ C	$r_{AC} = 5.0 \times 10^{-2}$ m	$k = 9.0 \times 10^9 \dfrac{\text{N}\cdot\text{m}^2}{\text{C}^2}$	$\vec{F}_{\text{net}}$
$q_B = -2.0 \times 10^{-6}$ C	$r_{BC} = 2.0 \times 10^{-2}$ m		
$q_C = +3.0 \times 10^{-6}$ C			

Develop a Strategy

Use Coulomb's law to find the magnitude of the forces acting on C.

$$F_{AC} = k\frac{q_A q_C}{r^2}$$

Let F_{AC} represent the magnitude of the force of charge A on charge C.

$$F_{AC} = \left(9.0 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(5.0 \times 10^{-6}\ \text{C})(3.0 \times 10^{-6}\ \text{C})}{(0.050\ \text{m})^2}$$

$$F_{AC} = 54\ \text{N}$$

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Let F_{BC} represent the magnitude of the force of charge B on charge C (attraction).

$$F_{BC} = k\frac{q_B q_C}{r^2}$$

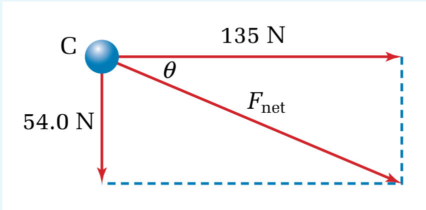
$$F_{BC} = \left(9.0 \times 10^9 \frac{N \cdot m^2}{C^2}\right)\frac{(2.0 \times 10^{-6}\ C)(3.0 \times 10^{-6}\ C)}{(0.020\ m)^2}$$

$$F_{BC} = 135\ N$$

Since charges A and C are both positive, the force will be repulsive and point directly downward on C.

Since B and C are oppositely charged, the force will be attractive and will point directly to the right of C.

Draw a diagram of the forces on charge C.



Use the Pythagorean theorem to calculate the magnitude of F_{net}.

$$F_{net}^2 = (135\ N)^2 + (54.0\ N)^2$$
$$F_{net}^2 = 21\ 141\ N^2$$
$$F_{net} = 145.39\ N$$
$$F_{net} \cong 1.5 \times 10^2\ N$$

Use the definition of the tangent function to find the angle, θ.

$$\tan\theta = \frac{54.0}{135}$$
$$\tan\theta = 0.40$$
$$\theta = \tan^{-1} 0.40$$
$$\theta = 21.8^\circ$$
$$\theta \cong 22^\circ$$

The net force on charge C is 1.5×10^2 N at an angle of 22° clockwise from the horizontal.

Validate the Solution

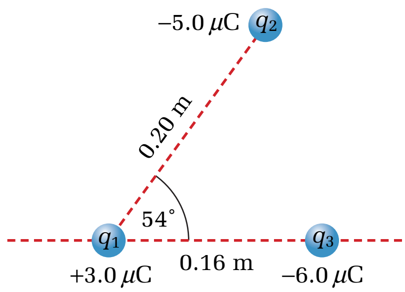
The magnitude and direction of the net force are consistent with the orientation of the three charges.

PRACTICE PROBLEMS

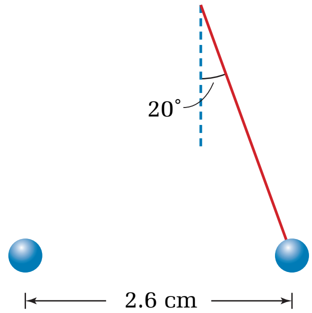
6. A single isolated proton is fixed on a surface. Where must another proton be located in relation to the first in order that the electrostatic force of repulsion would just support its weight?

7. Three charged objects are located at the vertices of a right triangle. Charge A (+5.0 μC) has Cartesian coordinates (0,4); charge B (–5.0 μC) is at the origin; charge C (+4.0 μC) has coordinates (5,0), where the coordinates are in metres. What is the net force on each charge?

8. The diagram shows three charges situated in a plane. What is the net electrostatic force on q_1?



9. The diagram below shows two pith balls, equally charged and each with a mass of 1.5 g. While one ball is suspended by a thread, the other is brought close to it and a state of equilibrium is reached. In that situation, the two balls are separated by 2.6 cm and the thread attached to the suspended ball makes an angle of 20˚ with the vertical. Calculate the charge on each of the pith balls.



10. Two 2.0 g spheres are attached to each end of a silk thread 1.20 m long. The spheres are given identical charges and the midpoint of the thread is then suspended from a point on the ceiling. The spheres come to rest in equilibrium, with their centres 15 cm apart. What is the magnitude of the charge on each sphere?

Although magnetic forces and electrostatic forces are related and both fit into the category of electromagnetic forces, the strength of a magnetic force cannot be defined in the same way as electrostatic and gravitational forces. The reason for the difference is that magnetic monopoles do not exist or, at least, have never been detected, in spite of the efforts of physicists. Where there is a north pole, you will also find a south pole. Nevertheless, Coulomb was able to approximate isolated magnetic monopoles by measuring the forces between the poles of very long, thin magnets.

If one pole of a long, thin bar magnet is placed in the vicinity of one pole of another long, thin bar magnet, Coulomb's magnetic force law states: The magnetic force F between one pole of magnetic strength p_1 and another pole of magnetic strength p_2 is inversely proportional to the square of the distance r between them, or $F \propto \frac{p_1 p_2}{r^2}$. It is not possible, however, to find a proportionality constant, because it is not possible to define a unit for p, a magnetic monopole.

You have seen that the three different types of forces — electrostatic, gravitational, and magnetic — all exhibit some form of an inverse square distance relationship. Are there any significant differences that you should note?

Probably the greatest difference between gravitational and electromagnetic forces is the strength. Gravitational forces are much weaker than electrostatic and magnetic forces. For example, you do not see uncharged pith balls, nor demagnetized iron bars, moving toward each other under the action of their mutual gravitational attraction.

In summary, the similarities and differences among electrostatic, gravitational, and magnetic forces are listed in Table 7.1.

Table 7.1 Differences among Electrostatic, Gravitational, and Magnetic Forces

Electrostatic force	Gravitational force	Magnetic force
■ can be attractive or repulsive ■ demonstrates an inverse square relationship in terms of distance ■ depends directly on the unit property (charge) ■ law easily verified using point charges (or equivalent charged spheres)	■ can only be attractive ■ demonstrates an inverse square relationship in terms of distance ■ depends directly on the unit property (mass) ■ law easily verified using point masses (or solid spheres) ■ magnitude of the force is much weaker than electrostatic or magnetic force	■ can be attractive or repulsive ■ demonstrates an inverse square relationship in terms of distance (between isolated poles) ■ depends directly on the unit property (pole strength) ■ law cannot be verified using magnetic monopoles as they do not exist independently (must be simulated using long, thin magnets or thin, magnetized wire)

7.1 Section Review

1. K/U What is meant by the statement that Coulomb "quantified" the electric force?
2. K/U In what way did Coulomb determine the dependence of the electrostatic force on different variables?
3. C Explain the similarities and differences between the Coulomb experiment for charge and the Cavendish experiment on mass.
4. C Explain how, in one sense, Coulomb's law is treated as a scalar relationship, but on the other hand, its vector properties must always be considered.
5. K/U State some similarities and some differences between the gravitational force and the electrostatic force.
6. MC Research the role of electrostatic charge in technology and write a brief report on your findings. Examples could include photocopiers and spray-painting equipment.
7. I By what factor would the electrostatic force between two charges change under the following conditions?
   (a) The distance is tripled.
   (b) Each of the charges is halved.
   (c) Both of the above changes are made.